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Charged Higgs effects on top spin correlations

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Work done with
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Top spin correlations

Top quark pairs at hadron colliders

- Spin configurations
  - Singlet, $S = 0$: $t_\uparrow \bar{t}_\downarrow$
  - Triplet, $S = 1$: $t_\uparrow \bar{t}_\uparrow, t_\uparrow \bar{t}_\downarrow, t_\downarrow \bar{t}_\downarrow$
- Different production modes (qq, gg) gives different configurations
- Measurement of spin projection of one top gives, statistically, the spin of the other top
- Parton level correlations:

$$\hat{C}_{ij}(M_{t\bar{t}}^2) = \frac{\hat{\sigma}_{ij}(t_\uparrow \bar{t}_\uparrow + t_\downarrow \bar{t}_\downarrow) - \hat{\sigma}_{ij}(t_\downarrow \bar{t}_\uparrow + t_\uparrow \bar{t}_\downarrow)}{\hat{\sigma}_{ij}(t_\uparrow \bar{t}_\uparrow + t_\downarrow \bar{t}_\downarrow) + \hat{\sigma}_{ij}(t_\downarrow \bar{t}_\uparrow + t_\uparrow \bar{t}_\downarrow)}$$

- Helicity basis, spin quantized along momentum of t ($\bar{t}$) in $t\bar{t}$ rest frame

Top spin correlations
continued

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- Parton level correlations

Threshold: $\hat{C}_{q\bar{q}}(4m_t^2) = -\frac{1}{3}$ $\qquad$ $\hat{C}_{gg}(4m_t^2) = 1$

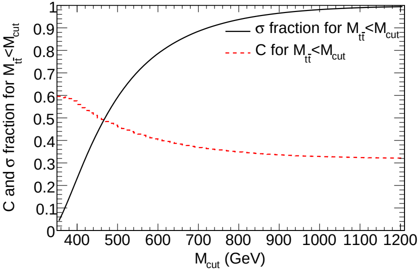
Relativistic limit: $\hat{C}_{ij}(M_{t\bar{t}}^2 \gg 4m_t^2) \to -1$

- Integrated correlations, NLO calculation [Bernreuter et al, Nucl.Phys. B690 (2004) 81-137]

Tevatron: $\mathcal{C} = -0.352$ $\quad$ $q\bar{q}$ dominated $\quad$ Still unmeasured

LHC: $\mathcal{C} = 0.326$ $\quad$ gg dominated

- Upper cut on $M_{t\bar{t}}^2$ gives more threshold like events
  - Higher correlations at LHC
  - Reduced statistics no problem since cross-section high



Measurement of spin and correlations

Top quark spin analyzing coefficients

- Fully polarized top quark at rest
- Spin along z-axis
- Weak decay, spin $\rightarrow$ angular distributions of decay products

$$\frac{1}{\Gamma}\frac{\mathrm{d}\Gamma}{\mathrm{d}\cos\theta_i} = \frac{1+\alpha_i\cos\theta_i}{2}$$

Analyzing particle	Analyzing coefficients α_i W^+ $(\omega = m_W^2/m_t^2)$	
b	$-\frac{1-2\omega}{1+2\omega}$	≈ -0.4
W^+	$\frac{1-2\omega}{1+2\omega}$	≈ 0.4
l^+ $(\bar{d})$	1	1
ν_l (u)	$\frac{(1-\omega)(1-11\omega-2\omega^2)-12\omega^2\ln\omega}{(1-\omega)^2(1+2\omega)}$	≈ -0.35

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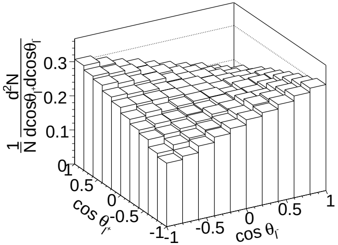
Measurement of spin and correlations

Spin correlations

- No net polarization of single top
- Use correlation

$$\frac{1}{N}\frac{\mathrm{d}^2 N}{\mathrm{d}\cos\theta_i\,\mathrm{d}\cos\theta_j} = \frac{1}{4}\left(1+\mathcal{C}\alpha_i\alpha_j\cos\theta_i\cos\theta_j\right)$$

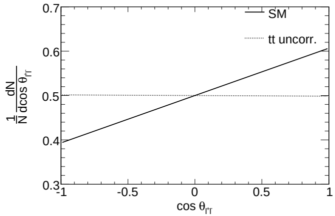
  - θ_i, θ_j, angles in respective top rest frame



- Alternative one parameter correlation

$$\frac{1}{N}\frac{\mathrm{d}N}{\mathrm{d}\cos\theta_{ij}} = \frac{1}{2}\left(1+\mathcal{D}\alpha_i\alpha_j\cos\theta_{ij}\right)$$

  - $\cos\theta_{ij} = \hat{p}_i \cdot \hat{p}_j$ is "opening angle"
  - Less sensitive to phase-space cuts



- $\mathcal{D}$ is related to $\mathcal{C}$
- NLO calculation gives $\mathcal{D} = -0.24$ at LHC

Charged Higgs in top decays

- Light charged Higgs meditate top decay
- Spin 0 $\rightarrow$ different spin analyzing coefficients
- Lagrangian for fermion part in 2HDM

$$\mathcal{L}_H = \frac{g_W}{2\sqrt{2}m_W} \sum_{\substack{\{u,c,t\}\\\{d,s,b\}}} V_{ud} \left\{ H^+ \bar{u} \left[A\,(1-\gamma_5) + B\,(1+\gamma_5) \right] d + h.c. \right. $$

$$+ \frac{g_W}{2\sqrt{2}m_W} \sum_{\{e,\mu,\tau\}} \left[H^+ C \bar{\nu}_l\,(1+\gamma_5)\,l + H^- C^* \bar{l}\,(1-\gamma_5)\,\nu_l \right].$$

- With couplings

Coupling	2HDM (I)	2HDM (II)
A	$m_u \cot\beta$	$m_u \cot\beta$
B	$-m_d \cot\beta$	$m_d \tan\beta$
C	$m_l \cot\beta$	$m_l \tan\beta$

Charged Higgs in top decays

Spin analyzing coefficients

Analyzing particle	Analyzing coefficients α_i W^+ $(\omega = m_W^2/m_t^2)$	H^+ $(\xi = m_{H^+}^2/m_t^2)$
b	$-\dfrac{1-2\omega}{1+2\omega}$	$-\dfrac{A^2-B^2}{A^2+B^2} f(\xi, A, B)$
W^+/H^+	$\dfrac{1-2\omega}{1+2\omega}$	$\dfrac{A^2-B^2}{A^2+B^2} f(\xi, A, B)$
l^+ $(\bar{d})$	1	$\dfrac{1-\xi^2+2\xi\ln\xi}{(1-\xi)^2} \dfrac{A^2-B^2}{A^2+B^2} f(\xi, A, B)$
ν_l (u)	$\dfrac{(1-\omega)(1-11\omega-2\omega^2)-12\omega^2\ln\omega}{(1-\omega)^2(1+2\omega)}$	$-\dfrac{1-\xi^2+2\xi\ln\xi}{(1-\xi)^2} \dfrac{A^2-B^2}{A^2+B^2} f(\xi, A, B)$

- Charged Higgs coefficients depend on $-\dfrac{A^2-B^2}{A^2+B^2}$
- Threshold factor $f(\xi, A, B) \simeq 1$ except for $m_{H^+} \to m_t$
- Remember in 2HDM(II): $A = m_u \cot\beta$ and $B = m_d \tan\beta$

Charged Higgs in top decays
Spin analyzing coefficients, continued

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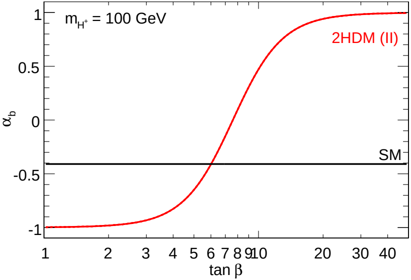
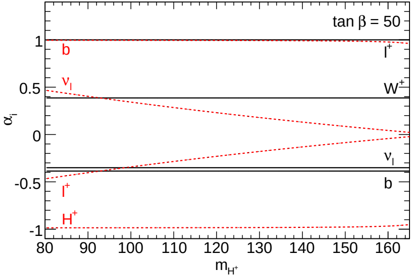
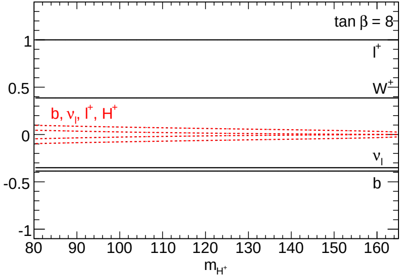
- l^+ most efficient particle in SM
- b and H^+ most efficient particles in 2HDM (II)
- Strong dependence on $\tan\beta$
- l^+ also depend on m_{H^+}



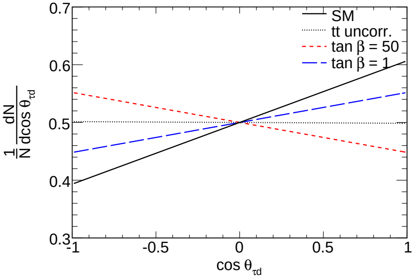


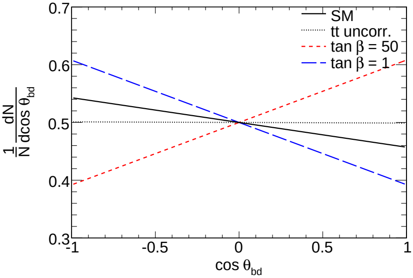


Parton level correlations
Best case

- $\begin{array}{ll} t \to b & H^+/W^+ \to b\,\tau^+\,\nu_\tau \\ \bar{t} \to \bar{b} & W^- \to \bar{b}\,\bar{u}\,d \end{array}$ + c.c. and α_i corresponding to $m_{H^+} = 80$ GeV
- $\mathcal{D}$-type correlations, $\mathcal{D} = -0.216$ at LHC

$$\frac{1}{N}\frac{\mathrm{d}N}{\mathrm{d}\cos\theta_{ij}} = \frac{1}{2}\left(1 + \mathcal{D}\alpha_i\alpha_j\cos\theta_{ij}\right)$$





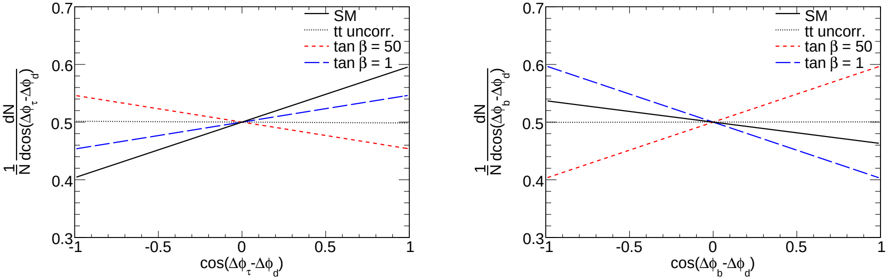
- Stable τ^+, fully know final state and CM frame

Parton level correlations
Azimuthal correlations

- Charged Higgs decays to $\tau^+ \, \nu_\tau$ and τ^+ to $X + \bar{\nu}_\tau$
- Center of mass frame not know
- Use hadronic W^+ and τ^+ to get transverse rest frame
- Use azimuthal angles and the correlation

$$\frac{1}{N}\frac{\mathrm{d}N}{\mathrm{d}\cos(\Delta\phi_i - \Delta\phi_j)} = \frac{1}{2}\left[1 + \mathcal{D}'\alpha_i\alpha_j\cos(\Delta\phi_i - \Delta\phi_j)\right].$$

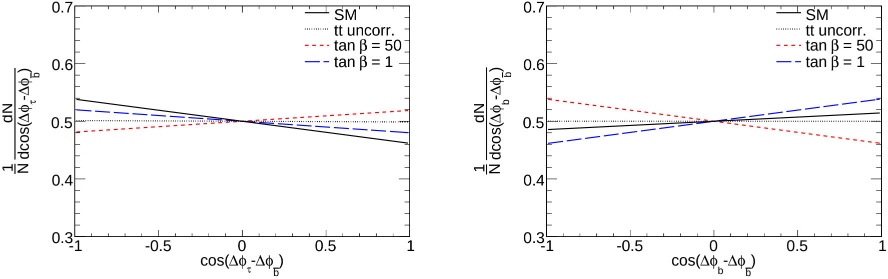
- Numerically $\mathcal{D}' = 0.9\mathcal{D}$ at LHC



Parton level correlations

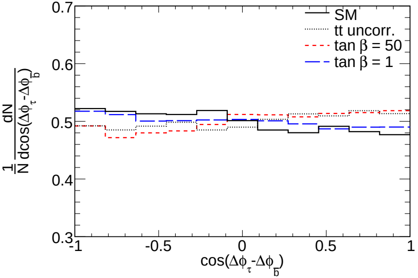
Azimuthal correlations, realistic variables

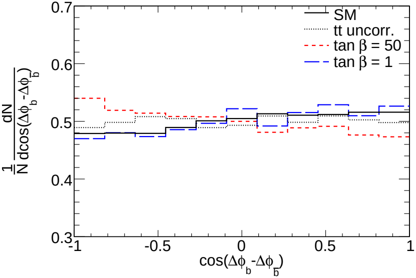
- Hard to identify *d*-jets
- Use *b*-jet (or least energetic light jet) on W^+ side
- Use τ^+-jet or *b*-jet on H^+ side
- Realistic best case, all quantities measurable



Hadron level correlations

- Full 2 $\rightarrow$ 6 ME with MadGraph/MadEvent
  $p\,p \rightarrow (t\,\bar{t}) \rightarrow (b\,H^+/W^+\,\bar{b}\,W^-) \rightarrow b\,\tau^+\,\nu_\tau\,\bar{b}\,\bar{u}\,d$
- τ^+ decay with Tauola
- Parton shower, hadronization and underlying event with Pythia
- $k_\perp$ jet finding in $|\eta| < 5$ with $d_{cut} = 20$ GeV
- "Flavor tag" $\Delta R(jet, truth) < 0.4$ in $|\eta| < 2.5$
- W^+ candidate $|m_{jj} - m_{W^+}| < 10$ GeV, t candidate $|m_{jjb} - m_t| < 15$ GeV
- No background or detector effects





Summary and Conclusions

- Top quark spin correlations should be measurable at LHC
- In SM l^+ is the most efficient analyzer
- Charged Higgs in top decays alter angular distributions
- In 2HDM(II) b quark is the most efficient analyzer
- Charged Higgs decays to τ^+ and neutrinos so full reconstruction not possible
- Correlations with azimuthal angles can be constructed, $\mathcal{D}'$
- Realistic hadron-level correlations are small in both SM and 2HDM(II)